AIRCRAFT PLYWOOD AND ADHESIVES

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The use of plywood in aircraft during World War I is briefly sketched, and the early limitations in its use, two of them important, are outlined. It is shown, that while plywood may be more inflammable than metal, the real fire hazard of an airplane is the gasoline; that the construction materials have very little influence on the personal safety factor. The deficiencies of the earlier glues have been overcome by the greater durability of the resin adhesives.

Two types of resin adhesives are described, the phenol formaldehyde type for plywood sheets and molded shapes that can be polymerized with adequate heat (300°F); and the urea formaldehyde group, that can be set at relatively low temperatures (70°F), which, however, can be accelerated by heating the clamped units at 120° to 140°F. It is pointed out that the phenolic bonds are boil proof, while those of urea are highly water resistant. Both are relatively immune to fungus growths.

High density plywood, frequently called super-pressed plywood or improved wood, is described as the product of a process that increases the strength and durability of wood, somewhat as the addition of alloys improves the metals.

The recently developed method of heating wood assemblies by diathermy is outlined, and its advantages in heat penetration into large wood units is recognized.

A number of solutions to aircraft design problems are suggested, indicating how the characteristic qualities of wood may be employed in improving aircraft performance. The inherent differences between wood and metal require distinct alterations in fundamental design, rather than the mere substitution of one material for the other.

The status of government specifications is outlined, with suggestions as to changes that are likely to occur.

A number of useful tables are included, converting the ANC-5 fundamentals into convenient working values, within the range of the more common aircraft plywood constructions.

The bibliography cites the more important publications and periodicals that are useful to students in the field of aircraft plywood.

In conclusion, the author points out that plywood, with the durable adhesives of recent development, presents many new and relatively undeveloped possibilities in the aircraft industry.

OUTLINE:

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3. Plywood Progress from 1920-30.
4. Phenol Formaldehyde Resin as a Plywood Adhesive.
5. Technique of Hot Pressed Resin Bonding. (Table 1.) (Figs. 1 & 2.)
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1. Historical

Plywood, as a structural material, has a utilization history of about fifty years. Decorative and artistic face veneers, always more or less fragile, had been reinforced by under layers of sturdy wood since the time of the Pharaohs in Egypt some 1500 B.C.

The design requirements of early aircraft, in the first decades of the present century, were the first real exploration of the strength/weight ratio advantages that have become so characteristic of well designed plywood. In fact, the term "Plywood" did not come into use until about this time. While plywood is made of veneer, the unfavorable and accumulated connotations of that word, obliged plywood advocates to establish the better and more descriptive title, plywood, which was particularly suited to strength factors of such a multi-layered product. Many other advantages of plywood, such as non-splitting, dimensional stability, distributed strength, cost, availability, ease of working, conservation of timber, facility for curving, bending and forming, need only be listed here, as they have been adequately described elsewhere. (5)*. With its many advantages in aircraft construction, there were a few limitations in plywood utilization that were recognized as serious handicaps in World War I.

2. Early Limitations to Plywood Utilization

One of the disadvantages that has been imputed to plywood, but quite incorrectly, was its tendency toward inflammability. It is perfectly apparent that the major hazard in flight is the gasoline fuel. If this becomes ignited, at any point, it matters little whether the plane is made of fabric, plywood, wood or metal, the results are equally disastrous. Experience has changed opinion on this point, due partly to better safeguards against fire, and it is no longer considered an unfavorable factor in the use of plywood as an aircraft material.

The other major limitation to wood and plywood construction, in this early period, was the character of the adhesives used in making the plywood and in assembling the wood and plywood parts. The adage of the weakest link in the chain, was a singularly accurate analogy to the quality of the adhesive used in the plywood.

In order to get perspective and intelligently evaluate the excellent plywood adhesives of the present time, it is important to briefly outline the background of the adhesives that were available at the time of World War I. At that period, casein (made from the curds of soured milk) and albumin (a dried blood product co-agulated under heat) were considered the most durable adhesives for aircraft construction. (11). Neither would withstand even an elementary mold and fungi test, in fact, under suitable conditions, both encouraged such parasitic growths. Casein plywood, bonded cold and tested dry, gave excellent bonds, and the addition of lime, up to 15%, improved its water resistance, but made it abrasive on edge tools. At best its resistance to continuous soaking and to alternate wet and dry tests was relatively low. It failed quickly in boiling water. Albumin plywood, hot pressed, possessed unusual water resistance, in fact could be soaked for many days, and would resist several cycles of wet and dry tests. It was not abrasive on tools, but it was found to deteriorate seriously with age.

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*Bibliography references are indicated by parenthetical ( ) numbers in the text.

3. Plywood Progress from 1920-30

In spite of these limitations plywood continued to be extensively used in aircraft for some years after the War, (9) but it was gradually displaced by metal. This was due, to a considerable extent, to the better co-operation between metal workers and the aircraft industry than was the case with the plywood makers. The metal advocates evidently were more research minded and more eager to develop the necessary scientific strength data than were the plywood group.

4. Phenol Formaldehyde Resin as a Plywood Adhesive

Soon after 1930, with the rapid growth of the plastic industry, resin adhesives began to attract the attention of the plywood industry. At first the phenol formaldehyde resin was only one available and that in film form (14) on an import basis. While only a few hot presses were available, the hot pressed resin plywood gave convincing evidence of far better durability than either casein or albumin, but the high import cost retarded the growth of the resin adhesive program.

By 1935 the demand for phenolic resin film was sufficiently urgent to justify domestic manufacture, which soon reduced the price to about half that of the imported supply, a typical American experience. (17). With this impetus, and the excellent durability characteristics that were found in Tego bonded plywood, the aircraft industry began to renew its interest in plywood. (18). These improved durability factors were:

1. Complete waterproofness, adhesive insoluble until wood decays.
2. High resistance to bacterial growth.
3. Boil proofness, facilitating bending and curving after steaming.

The liquid phenolics, developed several years after the films, were also found to possess the same durability characteristics. This development of phenolic adhesives removed the principal objection to the use of plywood in aircraft, indicated in Section 2 of this paper.

5. Technique of Hot Pressed Resin Bonding

The technique of bonding with film is definitely simpler than the mixing and spreading of a liquid, although both methods are practiced. The interleaving of the dimensioned film between veneers of 8 to 12% moisture content is the only preparatory step required. (28). In the case of a phenolic solution the successive steps of mixing, spreading and pre-drying (to prevent steam blisters in hot pressing) are necessary steps before pressing. In either event, the assembled sheets of veneer and adhesives are subjected to simultaneous heat and pressure for an interval varying from 5 minutes for 1/16" to 12 minutes for 5/16" plywood, at 300°F. and a pressure according to the density of the wood, from 125 lbs. sq. in. on spruce to 250 lbs. sq. in. on birch. Resin adhesive technique requires more care and precision than was considered necessary with the older glues.

The effect of the thickness of the veneer layer on the strength characteristics of the plywood shows some interesting trends, altho the test data is inadequate for other than general conclusions. (46). Table 1 gives the comparative results. The plywood samples were made of birch veneer under 500 lbs. specific pressure, somewhat higher than normal. It is to be observed improvement is negligible between 1/8" and 1/16" veneer, but conspicuous from 1/16" to 1/48". Interpolation would suggest that 1/30" veneer would give excellent strength increments, but this remains to be confirmed.

While the above procedure ordinarily applies to plywood made flat, it is equally practicable to preform (during the bonding operation) a wide variety of plywood shapes in pairs of heated metal dies, limited of course to such a range of shapes as will not rupture the veneer, the layers of which may be reinforced by thin cross layers or fabrics. Flat plywood, within reasonable limits, can be steamed thoroughly, formed and dried in wood or metal dies, the use of heat being optional and depending on the speed required. Bending without wood rupture can often be facilitated by placing veneer layers at 30 or 45 degrees to the axis of curvature. A wide range of constructions are available for use in bending operations, with variations in thickness of veneers, grain directions, compressibility factors and the like.

One of the earlier difficulties in aircraft plywood was the gummed tape that was used to hold the sheets of veneer together, edge to edge. The narrow ribbons of paper weakened the plywood joint, due to the tendency of the paper to delaminate. Edge gluing equipment for veneer has recently become available, using heat reactive resins. The details of this operation are shown in Figs. 1 and 2, of the infeed and outfeed ends of the machine. The liquid resin is applied to the edges of the veneer as it enters the gang of rollers, a brief drying interval follows, and the partly dried resin is cured by heat applied through the rollers at the outfeed end of the machine. The speed of operation on such machines maybe around 100 ft. per minute on thin veneers. The resulting edge joint is as strong as the veneer, and is difficult to distinguish. Such equipment is coming into quite general use in plywood factories.

6. High Density Plywood

The processes so far described apply to what is termed normal plywood, where the density of the wood may be somewhat increased by the addition of the resin and the slight compression (approximately 5-10%) of the veneers required to bring the surfaces into intimate contact for positive bonding.

Further compression, with higher specific pressures during the bonding operation, imparts an entirely new range of strength properties as can be noted in Table 2 and Figure 3. (46). The thickness of the test pieces was a full inch after compression, requiring additional sheets of veneer as the pressures were increased, as indicated in the third column of Table 2. The higher density samples were cooled thirty minutes before the removal of pressure. It is noticeable that the increases in specific gravity and strength were, in general, about double the increases in amounts of raw material required; except between 1,000 and 1,500 lb. pressures, where the improvement was not significant. In other words, both the table and chart indicate, that a distinctly lower rate of increase is to be expected over 1000 lbs. The tests were made on plywood from sheets of 1/48" birch veneer, with alternate layers crosslaid. Consequently the resin impregnation throughout the veneer was reasonably complete. It was discovered, somewhat unexpectedly, that poplar compressed under the same pressure, showed substantially the same specific gravity, and had approximately the same strength factors as birch. It required, however, 105 sheets of 1/45" poplar to produce a 1" thick sample of 1500 lbs. pressure. This would appear to indicate that wood at high densities is quite independent of original species characteristics.

This high density plywood can also be made by impregnating the veneers with a liquid phenolic resin, predrying and then hot pressing as in the case of film. (24, 25, 31). While this process is considerably more complicated, it will give a more complete impregnation. In general it may be said that the use of film results in wood reinforced with resin, with wood characteristics predominating, while the use of liquid resin produces a plastic reinforced with wood, more closely approaching the physical characteristics of plastics.

In both process the plywood, when soaked, tends to expand part way back towards its original thickness, but its absorptive capacity is far less than in normal plywood.

This favorable change in plywood strength characteristics through increase of density, is somewhat analogous to the alloying and heat treatment of metals to improve their qualities. It gives to wood workers an opportunity to meet design requirements that are far beyond the range of normal wood or normal plywood.

The strength characteristics of this high density plywood have been only partly explored and published (25, 26, 42). More work is in process and results will be published as fast as they are available.

Another type of high density plywood is in the experimental stage, impregnated with lignin, that is also polymerized under simultaneous heat and pressure. Little is known of its physical characteristics, but they probably are similar to those of the resin impregnated plywood. (44).

7. Assembly Adhesives

Plywood adhesives, as they have so far been considered, are adhesives that can be applied on veneers over large areas and bonded flat or curved, by the simultaneous application of heat and pressure. The most durable plywood, from all viewpoints, is that made with phenol formaldehyde resin adhesives. Adequate machinery has been developed so that flat and moderately curved plywood can be manufactured economically.

The other major adhesive problem in the aircraft program is that of the many manual operations of putting parts together, where a suitable adhesive is admittedly superior to any type of metallic fastener, such as nails, screws and bolts, etc. In this field casein had been found the best of the glues available up to the early 1930s when the last specifications (50, 51) were established for the assembly of airplane parts. Its serious limitations have become increasingly evident, especially in the last year, since plywood interest has again been awakened in the airplane industry. Casein may be as strong as the wood when dry and is water resistant, but delaminates after limited soaking in cold water, and very quickly in hot water. It is abrasive for cutting tools, and is low in resistance to bacterial growths.

Resin adhesives fortunately possess the good qualities and lack the poor qualities of the caseins. Dry bonds of both adhesives, if properly applied will break in the wood. Resins now available for airplane assembly purposes are sufficiently water resistant. Test samples after three months continuous soaking still retain over half of their shear strength. In the mold and fungi test casein is practically delaminated in the 10 day test, while suitable mixtures of resin pass the 10 day bacterial exposure with a 250 pound shear test. In the matter of abrasiveness the resins are far less damaging to edge tools than the caseins.

The phenolic resins, with the quality characteristics that have been outlined for plywood, have not yet found general favor in assembly work, as their low heat reaction is definitely inadequate. Fortunately another group of resins, of the urea formaldehyde type, are well adapted to assembly purposes. With a proper catalyst, the mixtures are stable or "live" for 4 hours after mixing, and will cure at room temperatures of 70°F., although the quality of the bond is improved and its cure accelerated by the application of heat up to 140°F. while under pressure, for a 4 to 8 hour period. These urea resins come in liquid form, which is reasonably stable for storage before catalyst is added; as well as in powder form, with catalyst incorporated, in which case the storage possibilities are definitely increased, provided the powder is protected from moisture. It is often advisable to use a small amount of relatively inert extender as a "body-maker" to reduce the absorption into the more porous species of wood. Pressures for this type of cold setting resins need only be enough to bring wood surfaces into intimate contact, or to slightly compress such a soft wood as spruce.

It has been pointed out that urea resins, with a cold setting catalyst, are benefited by elevated temperatures, up to approximately 130-140°F. One way to accomplish this is an air conditioned chamber, into which jigs, clamps and assemblies can be stored over the required period. In such cases it is important to guard against the drying of wood members, which should retain their normal moisture to preserve their resiliency. The wet and dry bulb readings, necessary to maintain an equilibrium moisture content are given in Table 3, over the required ranges. It is also a useful table for air conditioning of any wood shop.

A similar type of urea resin (34) is also available for hot pressing, where temperatures of 230°F. to 260°F. and specific pressures of 100 lbs. sq. in. and up, can both be obtained simultaneously, as in standard flat plywood. Its use, in aircraft plywood, however, is to be discouraged, since the phenolics give a more durable bond at slightly higher temperatures, and the phenolics are boil proof, heat proof and far more resistant to continuous and intermittent soaking.

8. Molded Airplanes and Sub-Assemblies

There has been much publicity on the subject of Plastic Planes, a somewhat inaccurate description, as the planes so far made have been molded plywood with resin adhesives and finishes, which hardly justify the use of the comprehensive term plastic plane. (48 b). The principles involved in moulding plywood are old, and the only novel features were the methods of applying the pressure as well as the unusually large size of the molded unit. The fundamental principle involved is that of using an inflated or deflated rubber bag as one of the halves of a pair of molding dies. There is not only the saving in matching up a pair of dies where the intermediate distance between halves must be very accurately determined, but in many cases the dies are wholly eliminated and, in any event, rubber bag pressure is of the order of fluid pressure and at substantially right angles to any surface that is under pressure. The Duramold, Timm and Vidal processes all utilize this rubber bag pressure principle.

Several of the more important applications of these rubber bag pressure principles are shown in Fig. 4. The upper sketch (Fig. 4-I) shows an early type of vacuum bag, used with cold setting glues, for the facing of wood core pilasters with veneers. The wood cores are accurately machined and very thin veneers are used. After the adhesive is applied, the parts are assembled and inserted in the rubber bag where the pressure is reduced to an approximate vacuum. While this pressure cannot exceed 15 lbs., the manual pressing and rubbing of the veneers against the cores, through the bag, will help to smooth out the curves. Quick-setting glues, of a tacky nature hasten this operation.

The next sketch (Fig. 4-II) indicates a method that has been used to mold half-fuselages. Here the inner mold may be made of metal or wood, and if metal may be provided with heating units. The outer shell must be of sheet metal, substantially cylindrical in shape, and firmly bolted to the base plate on which the inner mold rests. The wood parts, to be molded, may be of veneer or plywood, but must be cut to such tapers that each layer covers the preceeding completely and without laps. These parts must be held in approximate locations by tacks, (if a wooden mold), paper or cloth tape, steel bands, or wire. A deflated rubber bag, somewhat like an air mattress, is placed over the freshly spread wood layers, and the outer shell is dropped over the whole and bolted to the base. The rubber bag is then inflated with air, hot water or steam, and the wood layers are pressed and bonded together as well as to the frame members inserted in the mold. This method has been successful in making plywood hulls for small boats, using an inside mold of skeletonized wood, in which ribs are set flush for bonding to plywood.

Another process of molding plywood parts is shown in Fig. 4-III, in which a sub-assembly is enclosed in a rubber bag and the bag placed in a pressure tank. No vacuum is necessary here, merely a vent to atmosphere. The tank is usually filled with steam at 50 to 100 lbs. pressure. This method can be applied to such sub-assemblies as wings, aelerons, tail parts, etc., where plywood skin covering can be bonded direct to skeleton frame, spars, ribs, etc., without nailing, except the minimum necessary to hold parts in position until bonded.

The fourth type (bottom sketch Fig. 4-IV) is substantially the reverse of II, with a rubber bag placed inside rather than outside of the plywood to be bonded. It is useful where several layers of 2-ply are to be glued together after bending, and bonded into a rigid leading edge. This cannot be done in III, because of inadequate pressure where plywood is not supported by frame work. One of the distinct advantages of this outer-form-inner-bag method is the smoothness of the outside surface, with all irregularities occurring on the inside, adjacent to the bag.

These several molding methods have distinct possibilities, and there are many other possible combinations. The mechanical adaptations are not difficult, but the chief obstacle to broader use is the lack of standardization in aircraft design. There is no reason why these rubber bag methods should not find extensive use in airplane sub-assemblies, when and if some standardization becomes well established. Whether the processes will be adapted to large units like fuselage halves or complete planes is a problem that time and experience will reveal. The excellent weight/strength ratios of plywood and the smooth exteriors, without rivets, both add to the air effectiveness of such types of planes.

The resin adhesives are admirably adapted to these molded plane designs. If sufficient heat and pressure is attainable the phenolic liquid resins are preferable, while the urea resins will give good results if conditions are unfavorable for the use of phenolics.

9. High Frequency Electrostatic Methods

The conventional method for manufacturing aircraft plywood with synthetic resin adhesives has been the use of the steam heated platen in a hydraulic press. While entirely satisfactory on thin plywood, a definite limit in thicknesses appeared when time of heat penetration became excessive and the temperature gradient required to polymerize the resin in the central layers caused an overdrying of the outside layers.

This problem is well on its way toward solution by the utilization of high frequency electrostatic fields. The material to be heated is placed between the electrodes and experience indicates that suitable temperatures for resin cures can be obtained very quickly, even in the center of a block several inches thick. As a matter of fact, the temperatures attained by the wood are less than those that occur in the adhesive material. This process shortens the bonding time to such an extent that the wood layers suffer little loss of moisture content.

It is of course necessary to obtain the required specific pressures by mechanical means that are properly insulated.

This process is admirably adapted to such thick assemblies as the propeller blanks, described later, (25, 41), where heat penetration by the conventional method would be impossible. Whether it will be economic for thin plywood remains to be determined. It is also well suited to cure resin bonds expeditiously in wood and plywood sub-assemblies on jigs or even in various types of rubber bag assembly processes, heretofore described.

10. Wood and Plywood Constructions

There are fundamental differences in design requirements between wood and metal in aircraft construction. Wood has bulk and stiffness with high strength/weight ratios. Wood surfaces can be glued together. These facts give substance to the belief that molded plywood parts, with light, but strong arch effects, will be important factors in the aircraft of the future. Metal parts may be thinner and smaller for a given strength, but their attachment methods, by welding and riveting, are much more localized than the gluing together of wood parts over substantial areas. Obviously, the mere substitution of plywood for sheet metal, or vice versa, without fundamental design changes, may lead to serious difficulties. Maximum advantages for each material are only obtainable by intelligent utilization of wood experience on its designs and of metal knowledge on metal constructions.

(a) Laminated Spars. The term laminated refers to the parallel grains of the adjacent layers, while regular plywood has alternately crossed grains. A solid single piece of wood, of same size and species, is less desirable for aircraft work than a laminated piece of the same dimensions, since the fabrication permits balancing or bracing grain effects, reinforcement of adjacent layers, freedom from checking and more uniform moisture content. While spars for small "cub" planes are often solid wood, there is a distinct tendency to make them of laminated layers of sawn or sliced veneer. In general these spars are approximately 1" x 6" at the large end, tapered toward the small end, and in solid lumber seldom are available over 20 feet long. If laminated from 1/8" spruce, the lengths can be increased to almost any desired point by staggering and scarfing the splices as shown in Fig. 5. With a properly applied resin adhesive the quality of the laminate will be superior to solid spruce and the cost not out of line.

In larger types of trainer planes spars may either be made of overlaid 1/2" layers of solid wood or by aggregating pieces of laminated constructions as shown in Fig. 5. These large spars are often built up to 3" to 4" thickness at the fuselage ends, for reinforcing, while the layers taper or leaf-out toward the outer ends. Some spars are made of hollow beam construction toward the outer end, with thin diagonal plywood covering. Urea resin adhesives are suitable for all spar joints, while phenolic resins are preferable in the plywood used for covering.

(b) Plywood Ribs and Gussets. There is a wide range of constructions and designs possible here. (9). It should be kept in mind that, under column types of loading, solid wood often has a favorable strength/weight ratio over plywood, while for distributed strength and non splitting qualities plywood is far superior to solid wood. As in the case of the spar constructions, urea resins are best for assembly joints, while phenolic resins are to be preferred for joints in the plywood. In the case of such small areas as are involved in rib assemblies, sufficient pressure is often attainable by properly designed nails, with or without nailing strips, and sometimes by strong spring clamps. The important point is to bring surfaces into intimate contact.

(c) Skin Coverings of Plywood. One of the fundamental advantages of plywood is its stiffness/weight factor, which can be simply illustrated as follows:- Aluminum sheets have a specific gravity of 2.8 approximately, while spruce plywood has a corresponding characteristic of .5 to .6. Hence for an equal weight, plywood can be four to five times as thick, or for equal thickness, plywood is correspondingly lighter. Plywood can be glued to the ribs and spars, while metals have to be riveted, a distinct disadvantage. The springiness of plywood renders it less easily damaged and if damaged it is much simpler to repair.

Certain combinations of plywood thickness and curvature can be bent cold and dry. If the curve is too severe, Tego bonded plywood can be softened by steaming and then bent and dried over either a single or double form, which may be heated. Sometimes rather sharp curves are facilitated by bending at 45° with the face of the plywood, rather than parallel to any layer within the plywood. It is becoming increasingly apparent that thicker skin coverings, at such locations as leading edges, may permit the elimination of a substantial number of ribs, with consequent reductions in time, weight and cost. In some cases these thicker plywood surfaces may consist of several layers of 2-ply, bonded together as suggested in Fig. 4-IV, with rubber bag pressure.

(d) High Density Reinforcing Plates. Solid lumber, such as the spruce used in spars, splits easily and has very low bolt holding power. Hence spruce spars require sturdy reinforcement where they are attached to the fuselage or landing gear. While this is often done with metal plates, it is possible to get very excellent results from the use of reinforcing plates of high density plywood, of which the strength characteristics are given in Table 2. (46). It is to be noted that the resistance to shear is increased some seven fold, as between solid wood and plywood pressed at 1000 or 1500 lbs. specific pressure. While both solid maple and normal pressed plywood (200 lbs. p.s.i.) are used for such reinfacing, the denser product offers distinct advantages in the weight/shear ratio, i.e. where shear resistance increases some 700%, the specific gravity or weight only increases 114%.

One important factor in using high density plywood for reinforcing plates is to have the surface, adjacent to the soft wood, sufficiently roughened so that the bond will be both mechanical and adhesive. A simple way to accomplish this is to have one surface of the high density plywood pressed (as it is made) against a knurled plate, or even against a properly proportioned metal screen, so that the resulting ridges and valleys are from 1/32" to 1/16" high and not farther than 1/8" apart. Such a roughened surface can be pressed into the spruce by the bolts and will result in a mechanical grip of unusual strength.

While the spar is the most obvious place on which to use high density plywood reinforcing plates, with mechanical interlocking into the wood surfaces, there may be other locations where such strength developments can be utilized to definite advantage.

(e) Propeller Constructions. Progress in the propeller field is rapid, and it would be venturesome to predict the extent to which wood and plywood, with its newly developed attributes of high density may enter the field of propeller design.

At the present time many, if not most, of the double blade straight propellers for "cub" planes are laminated wood, built up out of 3/4" birch, mahogany or walnut lumber, and this type of construction seems well established.

As the service becomes more exacting on larger planes of the various trainer types, there is a tendency to use two single blades, mounted on a straight line, in metal hubs provided with clamps that permit adjustment of pitch, on the ground, but are in fixed position during flight. Here plywood fits the requirements adequately, and the blanks may be made with high density at the hub end and low at the tip, as is outlined below for larger sizes.

Large single propeller blades have been made of wood, using strips 1/2" thick, that are very dense "Jicwood" or "Pregwood" at the hub end. (41). This dense portion is scarfed onto spruce for lightness toward the tip end, where gripping power is not essential. These laminae are built up into suitable blanks for blades that may approach 12" in width and 10' 0" in length.

Another type of propeller construction is built up from 1/2" thick laminae made on a variable density basis as shown in the upper sketch of Fig. 6. The veneer layers (25) are varied in length to give such density as strength requirements may dictate at any section in the propeller. In general the aggregate thickness at the hub end will be some 175% of the final thickness and at the tip approximately 115%. The whole is hot pressed, with Tego Film, to a uniform thickness controlled by metal thickness separators in the press. The density requirements may be varied by the species, the bulk and the pressure. In some instances it may be desirable to cross lay the shorter layers of veneer, but this will depend on design requirements. These 1/2" laminae are then built up into the desired size blank, of which a type is shown in the lower sketch of Fig. 6. The dotted lines indicate approximately the final shape.

Developments in wood propeller design are likely to become increasingly important in the near future.

11. Status of Government Specifications

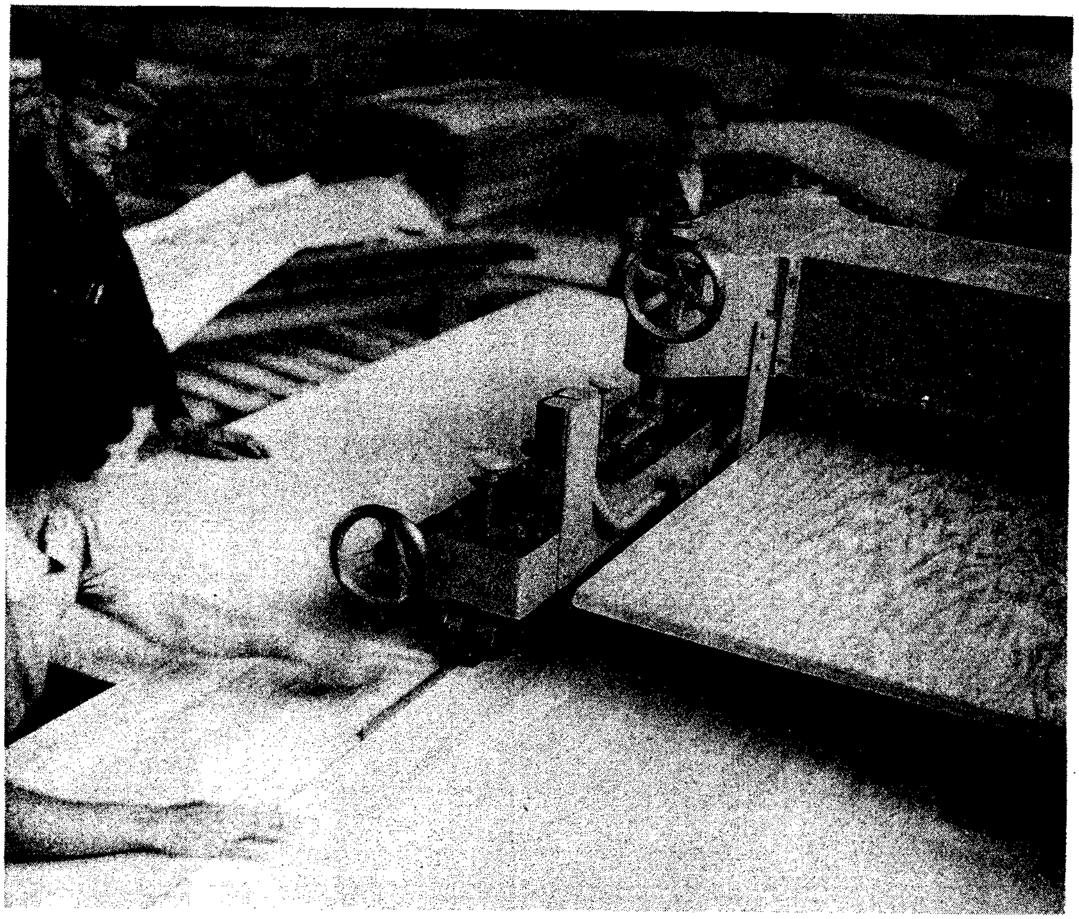
The Army and Navy specifications for aircraft plywood have been combined in AN-NN-P-511 (49) and stipulate two grades of plywood, Standard and Waterproof. In the latter, the soaking and fungus tests eliminate all adhesives except the resins.

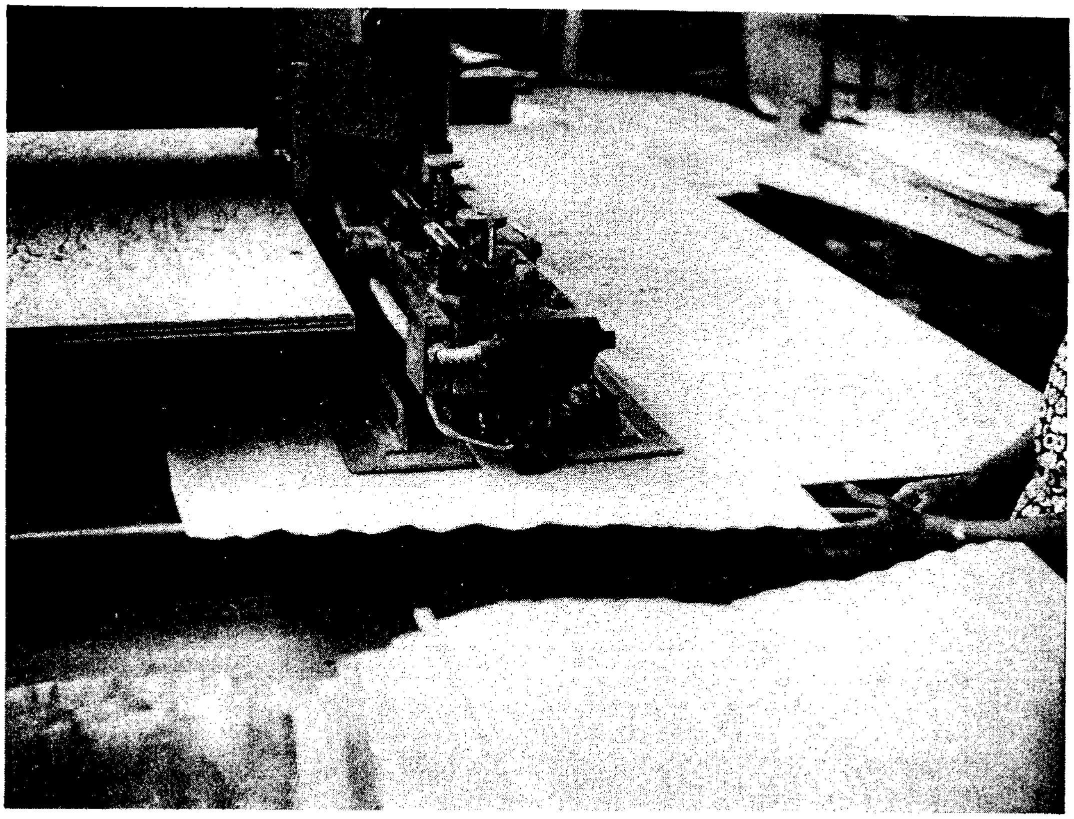
In the matter of assembly adhesives, the Army and Navy publish separate specifications, which are cited in the Bibliography.

12. Physical Properties of Plywood

Fundamental data on the strength characteristics of solid wood are well established. It should be noted that the behavior of wood under stress loadings is sometimes quite different from that of metals, since wood is relatively non-homogeneous, while most metals are quite homogenous. Most technical information on the strength of materials has been in the metal field and has been based on the behavior of metals. Since wood reacts quite differently from metal in some respects, it is not always possible to consistently compare the performance of wood and metal. And as a consequence some of the desirable qualities of wood have not been adequately recognized.

Plywood, while depending for its strength characteristics on the strength elements of the various sheets of veneer of which it is composed, still presents several new qualities of distinct value. In addition there are many principles of design and types of construction in plywood that, under intelligent application, can be utilized to secure special strength requirements that far exceed the normal in either wood or plywood. It is for this reason that plywood offers unusual advantages to the





Figs. 1 and 2. EDGE SPLICING VENEER WITHOUT TAPE.

Photos by courtesy Plycor Company, Chicago

Fig. 1. Infeed side of splicing machine.
Fig. 2. Delivery side in lower photo.

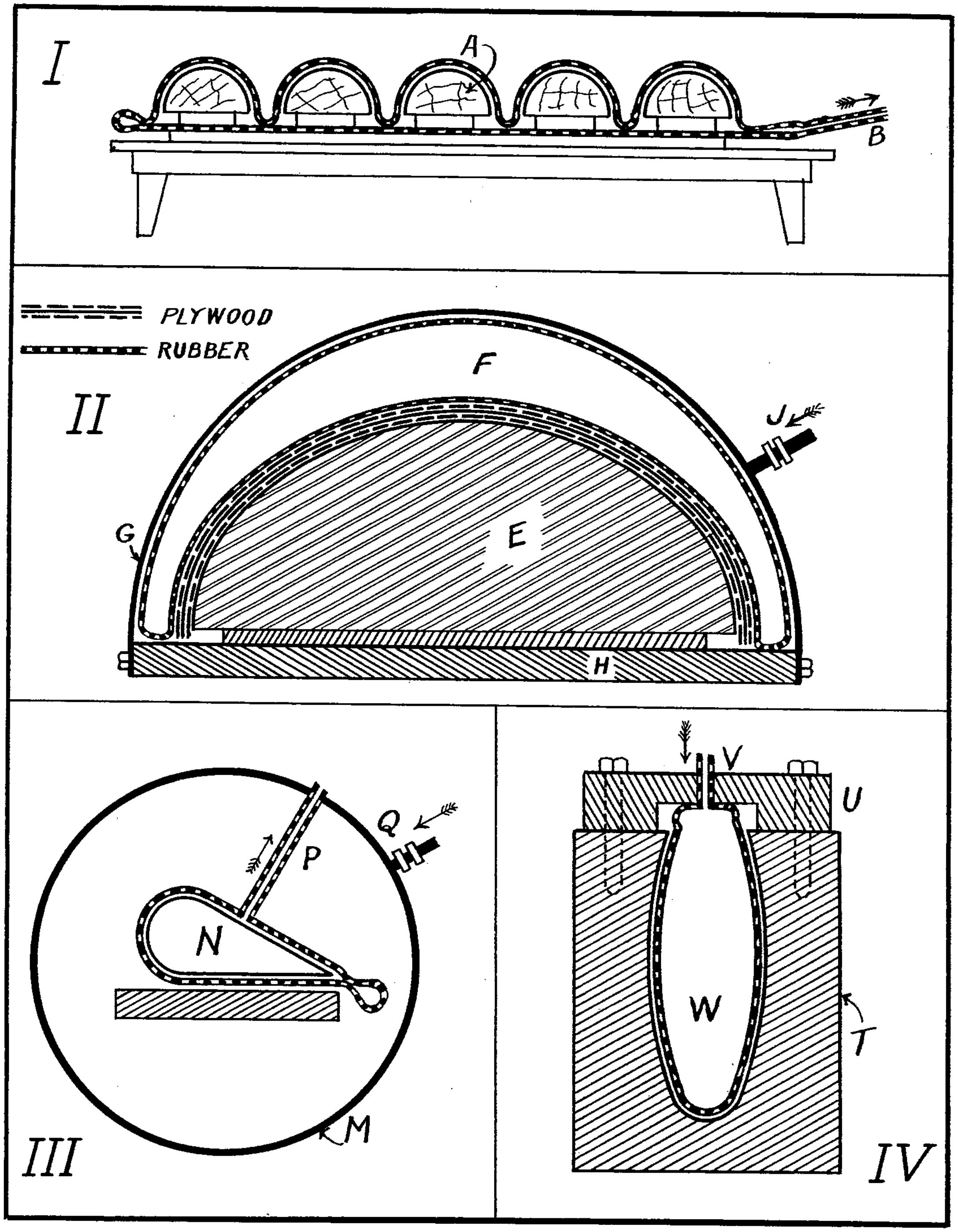


Fig. 4. MOLDING PROCESSES FOR AIRCRAFT.

Typical diagramatic sections, no scale.

Using Rubber Bag Pressures.

I **Molding with Vacuum Bags.**

- A. Solid wood pilasters to be veneer faced.
- B. Vacuum exhaust outlet.

II **Molding a Half Fuselage.**

- E. Inside mold, may be metal with steam pipes, or framed wood with slots for rings and longerons.
- F. Rubber bag, inflated with air, steam or hot water, through inlet J.
- G. Outer steel shell, bolted to base H.

III **Molding Sub Assembly Parts in Pressure Tanks.**

- M. Outer steel tank.
- N. Sub Assembly, inside of rubber bag.
- P. Vent to atmosphere, or vacuum connection.
- Q. Pressure connection for steam.

IV **Molding with Internal Bag Pressures.**

- T. Outside mold, metal or heavy wood frame. If of metal may be steam heated.
- U. Sturdy cap, bolted to T.
- V. Inlet for air, steam or hot water.
- W. Rubber bag, inside of sub assembly.

TABLE 1.
Effect of Veneer Thickness on Plywood Strength.

Plywood bonded with Tego Phenolic Film at 500#, with alternate cross layers.

Key	Veneer Thickness	Layers Used	Specific Gravity	Compression	Tension	Shear
A	Solid Birch	1	.63	6,200 *	10,100 *	2,020 *
B	1/8" Birch	9	.77	7,890	11,840	6,060
C	1/16" Birch	17	.72	7,980	13,920	6,330
D	1/48" Birch	69	1.05	11,720	19,160	11,540
Increases						
	D over A*	-	67%	89%	90%	470%
	D over B	-	46	49	62	90

TABLE 2.
Effect of Increasing Bonding Pressure in Plywood.

Plywood of 1/48" birch veneer, with
alternate cross layers, using single
sheets of Tego Resin Film.

Key	Construction	Layers Veneer	Specific Gravity	Specific Pressure	Compression	Tension	Shear
A	Solid Birch	-	.63	-	6,200 *	10,100 *	2,020 *
B	Birch Plywood	57	.77	200	8,580	12,550	7,240
C	Birch Plywood	69	1.05	500	11,720	19,160	11,540
D	Birch Plywood	81	1.30	1,000	14,220	25,740	16,180
E	Birch Plywood	85	1.35	1,500	14,410	26,760	16,130
Increases							
	B over A*	-	22%	-	38%	24%	258%
	E over A*	-	114	-	132	166	700
	C over B	21%	36	-	37	53	59
	D over B	42	69	-	66	105	124
	E over B	49	77	-	68	114	122
	D over C	17	24	-	21	34	40
	E over C	23	29	-	23	40	40
	E over D	5	4	-	1	4	0

Pressures and strength factors in pounds per square inch.

* Strength factors of solid wood and plywood not strictly comparable, but this fibre stress at the proportional limit in solid wood is the most available figure to compare with breaking stresses in plywood of this type.

Table 3.

EQUILIBRIUM MOISTURE CONTENT OF WOOD PRODUCTS

At Various Fahrenheit Temperatures

Dry and Wet Bulb Readings

Dry Bulb Temperatures Fahrenheit	Equilibrium Moisture Content of Wood											
	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
	Wet Bulb Temperatures, Fahrenheit											
50°	34°	36°	38°	39°	40°	41°	42°	43°	44°	45°	46°	46°
55	39	41	42	43	45	46	47	48	49	50	50	51
60	43	44	46	47	49	50	51	52	53	54	55	56
65	46	48	49	51	53	54	56	57	58	59	60	60
70	50	51	53	55	57	58	60	61	63	64	64	65
75	53	55	57	59	61	63	64	66	67	68	69	70
80	56	58	60	63	65	67	69	70	72	73	74	75
85	59	63	64	66	69	71	73	75	76	77	78	79
90	--	65	68	70	73	76	78	79	81	82	83	84
95	--	69	72	75	78	80	82	84	85	87	88	89
100	--	--	76	79	82	85	87	89	90	92	93	94
105	--	--	80	83	86	89	92	94	95	96	98	99
110	--	--	84	88	91	94	96	98	100	101	103	104
115	--	--	--	92	96	99	101	103	105	106	107	109
120	--	--	--	97	100	103	106	108	110	111	112	114
125	--	--	--	102	105	108	111	113	115	116	118	119
130	--	--	--	107	110	113	116	118	120	121	123	124
135	--	--	--	111	115	118	121	123	125	127	128	129
140	--	--	--	116	120	123	126	128	130	132	133	134
145	--	--	--	121	125	128	131	133	135	137	138	139
150	--	--	--	126	130	133	136	138	140	142	143	144
155	--	--	--	131	135	139	142	144	146	147	148	150
160	--	--	--	136	140	144	147	149	151	152	154	155
165	--	--	--	141	145	149	152	154	156	158	159	160
170	--	--	--	146	151	154	157	159	161	163	164	166

Examples:

A What air conditions are required to maintain veneer at 10% M.C. for Tego film bonding? At 90°F dry bulb, set humidifier for 78°F on wet bulb.

B In an oven, where clamped cold set resin assemblies are placed over night, if M.C. of the wood is to be kept at 12%, and oven heat is 130°F (dry bulb); set regulator for wet bulb of 120°F.

10/16/40

Table 4. PLYWOOD WEIGHTS

Computed on Haskelite constructions.

Species of) Face and Back			Birch	Birch	Mahogany	Poplar (3)
) Other Plies			Birch	Poplar	Poplar	Poplar
Thickness		Number of Plies	Estimated Weights per Sq. Ft.(1)			
Nominal	Limits					
3/64 inch	.040-.058 in.	3	.21	(2).21	.18	.17
1/16	.055-.075	3	.30	.25	.22	.20
3/32	.085-.105	3	.40	.35	.29	.27
1/8	.115-.135	3	.52	.43	.37	.35
5/32	.145-.170	3	.60	.50	.43	.40
3/16	.170-.200	3	.71	.58	.50	.47
3/16	.170-.200	5		.58	.53	.50
7/32	.205-.235	5		.74	.65	.62
1/4	.235-.265	5		.80	.71	.68
5/16	.300-.325	5		.95	.84	.80
3/8	.360-.390	5		1.05	.97	.93
7/16	.420-.460	7		1.30	1.19	1.15
1/2	.480-.520	7		1.47	1.36	1.32
9/16	.545-.580	7		1.62	1.47	1.41
5/8	.600-.650	9		1.96	1.70	1.59
3/4	.725-.775	9		2.35	2.01	1.88
1 mm	.029-.049	3	.17			
$1\frac{1}{2}$	.049-.069	3	.28	.24	.21	.20
2	.069-.089	3	.37	.33	.27	.25
3	.108-.128	3	.52	.43	.37	.35

Explanatory Notes to Table 4.

(1) Nominal weights given in this table are based on the exact veneer thicknesses required, the glue weighing .013 lb. per sq. ft. of glue joint, and the weight of the wood in pounds per cubic feet as follows:

Birch	43.3 lbs	Poplar	28 lbs
Mahogany	32.2	Spruce	27

The moisture content of the plywood is assumed to be 12%.

(2) The weights for the 3/64" thickness are based on birch being used for the core. United States Army and Navy specifications (49) call for all plies of birch in case of any panel under 1/16" thickness.

(3) The weights given for poplar plywood are, for all practical purposes, the same as for spruce plywood.

Explanatory Notes on Table 6.

Each characteristic applies to a strip of the panel one inch in width in which the face grain is either longitudinal (Long.) or transverse (Tran.). The strip is bent in a plane perpendicular to the face.

Stiffness (EI) is expressed in $(\text{in.})^2$ lb. The basic moment gives a stress of 1000 lb./sq.in. in the outermost fiber whose direction is parallel to the length of the strip. It serves the purpose of section modulus. It is expressed in inch-pounds. When the strip is bent to the elastic radius - expressed in inches - the maximum fiber stress reaches the assumed elastic limit in bending. For permanent bending, plywood should be moistened or steamed.

The tabulated values are based upon the following properties of the species of wood, all in lb./sq.inch: Modulus of Elasticity along the grain - 1,960,000 for Birch; 1,390,000 for Mahogany; 1,430,000 for Poplar and 1,430,000 for Spruce. Elastic limit in Bending - 9,500 for Birch; 8,800 for Mahogany; 6,000 for Poplar and 6,200 for Spruce.

These are found in ANC-5, STRENGTH OF AIRCRAFT ELEMENTS, (52) Table 2-1, on page 2-8, but the values of E have been increased 10% in accordance with note #2 of this table. The modulus of elasticity across the grain is taken as 5% of the value along the grain.

In making the panels, the veneers are compressed. It has been assumed that the thickness of each panel is precisely the nominal value, and that all its veneers are compressed by the same percent. To obtain the tabular values, the moduli of elasticity have been increased in proportion to this compression.

The tabulated values shown for Poplar plywood are, for all practical purposes, the same as for Spruce plywood; however, it must be remembered that Spruce surpasses Poplar in absorption of work in bending. See Column 10 of table 2-1, on page 2-8 of ANC-5. (52)

Table 5.

ESTIMATED TENSILE STRENGTH AND BEARING STRENGTH OF AIRCRAFT PLYWOOD.

Based and computed on Haskelite Construction.

Species of...		Face and Back....Birch Other Plies......Birch		Birch Poplar		Mahogany(b) Poplar		Poplar (d) Poplar	
Nominal Thickness	Number of Plies	Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.
		Estimated Tensile Strength -- lb./ per inch width (a)							
3/64 inch	3	600	440	600	260	300	240	340	250
1/16	3	820	730	810	430	430	390	470	420
3/32	3	1210	880	1200	530	620	470	680	520
1/8	3	1270	1420	1260	820	680	760	740	810
5/32	3	1670	1670	1660	970	880	890	970	970
3/16	3	2000	2000	1990	1170	1050	1075	1160	1160
3/16	5			1660	1170	1085	1100	1140	1160
7/32	5			2740	1060	1800	970	1910	1050
1/4	5			2790	1340	1860	1230	1960	1320
5/16	5			3400	1420	2240	1300	2370	1410
3/8	5			3150	2340	2220	2230	2320	2320
7/16	7			3900	2720	2730	2600	2870	2700
1/2	7			4370	3160	3210	3040	3340	3140
9/16	7			5120	3250	3510	3090	3740	3230
5/8	9			5230	3570	4070	3440	4190	3550
3/4	9			6290	4410	4740	4250	4900	4390
1 mm.	3	470	420	460	250	240	230	250	250
1½ "	3	810	650	800	390	420	340	460	380
2 "	3	1190	690	1180	430	600	370	660	420
3 "	3	1270	1420	1260	820	680	760	740	810
		Estimated Bearing Strength - lb./per inch width. (c)							
3/64 inch	3	230	154	221	110	202	115	154	106
1/16	3	307	269	298	182	269	192	202	182
3/32	3	451	317	442	221	394	221	307	211
1/8	3	461	528	451	365	403	374	317	355
5/32	3	614	614	595	432	538	432	413	413
3/16	3	739	739	720	518	643	518	499	499
3/16	5	720	739	624	509	576	509	490	499
7/32	5	1306	566	1114	394	1037	403	893	374
1/4	5	1325	768	1123	538	1046	538	902	518
5/16	5	1613	787	1373	547	1277	547	1094	518
3/8	5	1478	1478	1219	1018	1142	1018	998	998
7/16	7			1517	1171	1421	1171	1238	1142
1/2	7			1728	1363	1632	1363	1450	1334
9/16	7			2016	1373	1891	1382	1651	1344
5/8	9			2131	1498	2035	1498	1853	1469
3/4	9			2515	1872	2390	1882	2150	1843
1 mm.	3	173	154	168	110	149	110	115	106
1½ "	3	307	230	298	168	249	168	202	158
2 "	3	451	240	442	173	394	178	307	163
3 "	3	461	528	451	365	403	374	317	355

These strength values apply only to aircraft plywood, made under Type II of the U. S. Army and Navy Specifications (49)

Explanatory Notes to Table 5.

(a) In ANC-5, (52) "Strength of Aircraft Elements", tabel 2-2, on page 2-8, reports tests made upon tensile strength of plywood panels of 35 species of wood. Each panel had three plies of the same thickness and of the same species. Strength of two kinds are reported, (1) for tension parallel to the face grain and (2) for tension perpendicular to the face grain. The results are expressed in pounds per square inch of the complete section, and they may be called T_1 and T_2 respectively.

Let us use T_L and T_T to represent the tensile strength of the veneer, T_L along the grain and T_T across the grain. Then we should have

$$T_L = 2T_1 - T_2 \qquad \text{and} \qquad T_T = 2T_2 - T_1$$

The tensile strength used as a basis for the above tabulation has been obtained in this manner from the values given in ANC-5, (52), and are:

Birch . . $T_L = 18,700$; $T_T = 2,200$. Mahogany . $T_L = 9,000$; $T_T = 1,170$
Spruce . $T_L = 7,950$; $T_T = 900$. Poplar $T_L = 10,060$; $T_T = 2,050$

all in pounds per square inch.

(b) The estimated tensile strengths given for Mahogany plywood, are for all practical purposes, the same as for Spruce plywood.

(c) The bearing strength values tabulated above are based upon the following values assumed for Haskelite plywood in pounds per square inch:

	Birch	Mahogany	Poplar	Spruce
Bearing strength along grain of veneer	7,300	6,500	5,000	5,000
Bearing strength across grain of veneer	400	440	200	220

The above unit bearing values, along the grain, reproduce values given in column 12 of table 2-1, page 2-8 of ANC-5 (52), "Strength of Aircraft Elements". To obtain the above unit bearing values across the grain, the values given in column 13, of the above reference, have been divided by four, because of such different strains involved in bringing wood up to maximum bearing, depending upon the direction of the grain.

(d) The estimated bearing strengths given for poplar plywood, are for all practical purposes, the same as for Spruce plywood. Compare the bearing strengths of the two woods as shown in the above footnote.

Table 6. PLYWOOD BENDING CHARACTERISTICS.

Computed on Haskelite construction

Nominal Thickness	Number of Plies	Stiffness EI		Basic Moment 1000 lb. per sq. in.		Elastic Radii	
		Long.	Tran.	Long.	Tran.	Long.	Tran.
		ALL PLIES BIRCH					
3/64 inch	3	16.9	2.0	.35	.10	5.1"	2.0"
1/16	3	42.9	6.7	.59	.20	7.6	3.5
3/32	3	134	15.9	1.37	.42	10.4	4.1
1/8	3	282	65	2.22	.95	13.3	7.1
5/32	3	560	107	3.57	1.36	16.5	8.3
3/16	3	970	186	5.16	1.98	19.8	9.9
1 mm.	3	9.7	1.6	.23	.08	4.4	2.1
1½ "	3	36.8	4.9	.54	.17	7.2	3.1
2 "	3	88	7.7	1.00	.26	9.28	3.1
3 "	3	257	52	2.28	.80	13.3	6.8
		FACES BIRCH - OTHER PLIES POPLAR					
3/64 inch	3	16.8	1.7	.34	.12	5.1	2.4
1/16	3	42.9	5.5	.59	.22	7.6	4.1
3/32	3	134	13.4	1.37	.47	10.4	4.7
1/8	3	280	50.9	2.22	1.03	13.3	8.3
5/32	3	560	86	3.6	1.5	16.5	9.5
3/16	3	969	148	5.1	2.17	19.8	11.4
3/16	5	800	288	4.3	3.1	23.0	19.6
7/32	5	1540	336	6.5	3.2	25.2	17.7
1/4	5	2100	600	7.9	4.8	28.0	20.9
5/16	5	3960	940	12.9	6.8	32.0	22.8
3/8	5	5300	2870	14.1	13.9	39.6	34.4
7/16	7	9300	4580	20.7	16.8	47	40
1/2	7	13600	6490	26.2	21.7	55	49
9/16	7	20700	7400	37.0	25.0	60	50
5/8	9	25000	11400	40	31.0	67	62
3/4	9	44100	20100	59	46.0	79	72
1 mm.	3	9.7	1.3	.23	.09	4.3	2.4
1½ "	3	36.8	4.1	.53	.19	7.2	3.6
2 "	3	87.9	6.8	1.00	.32	9.3	3.6
3 "	3	256.	41.3	2.23	.87	13.3	7.8
		FACES MAHOGANY; OTHER PLIES POPLAR					
3/64 inch	3	11.9	1.4	.34	.10	4.0	2.4
1/16	3	30.5	4.9	.59	.20	5.9	4.1
3/32	3	95	11.4	1.37	.40	7.9	4.7
1/8	3	200	46.8	2.22	.94	10.2	8.3
5/32	3	398	77.8	3.6	1.36	12.6	9.5
3/16	3	690	135	5.2	1.97	15.2	11.4
3/16	5	586	278	4.4	3.0	15.1	15.6
7/32	5	1110	316	6.6	3.0	19.3	17.7
1/4	5	1510	576	8.0	4.5	21.5	20.9
5/16	5	2850	980	13.1	6.4	24.7	22.8
3/8	5	3840	2790	14.4	13.6	30.3	34.4
7/16	7	6910	3970	21.5	16.3	36.4	40.5
1/2	7	9600	6310	27.4	21.3	42.2	49.5
9/16	7	15300	7100	38.0	24.0	45.5	49.6
5/8	9	19500	11100	44	30.0	50.6	52.4
3/4	9	33600	19500	58	45.0	60.7	72.5
1 mm.	3	6.9	1.2	.23	.08	3.4	2.4
1½ "	3	26.1	3.6	.54	.17	5.5	3.6
2 "	3	62.5	5.6	1.00	.26	7.1	3.6
3 "	3	182	37.4	2.38	.80	10.6	7.8
		ALL PLIES POPLAR					
3/64 inch	3	12.3	1.4	.34	.10	6.0	2.4
1/16	3	31.4	4.9	.59	.20	8.9	4.1
3/32	3	98	11.6	1.38	.40	11.9	4.8
1/8	3	204	47.1	2.22	.95	15.4	8.3
5/32	3	409	78	3.6	1.36	19.0	9.5
3/16	3	710	136	5.2	1.98	22.8	11.4
3/16	5	600	278.4	4.4	3.0	22.7	15.6
7/32	5	1140	316.8	6.5	3.0	33.0	17.7
1/4	5	1560	576	8.0	4.6	32.4	20.9
5/16	5	2930	880	13.1	6.4	37.1	22.8
3/8	5	3950	2800	14.4	13.6	45.8	34.1
7/16	7	7000	3980	21.4	16.3	54.8	40.5
1/2	7	9980	6300	26.9	21.3	63.8	49.5
9/16	7	15600	7100	38.0	24.0	68.6	49.6
5/8	9	19900	11100	44	30.0	76.3	62
3/4	9	34500	19600	63	45.0	43.5	72
1 mm.	3	7.1	1.2	.23	.08	5.1	2.4
1½ "	3	26.8	3.6	.54	.17	8.4	3.6
2 "	3	64.2	5.7	1.00	.27	10.7	3.6
3 "	3	188.0	37.6	2.40	.80	15.4	7.9

These strength values apply only to aircraft plywood, made under Type II of the U.S. Army and Navy Specifications (49).

Table 7.

PREDETERMINATION OF STRENGTH VALUES OF HIGH DENSITY BIRCH PLYWOOD.

Type of Stress	Veneer Thickness	Cross Layers Veneer	Tego Film Layers	Specific Gravity	Specific Pressure Lb.Sq.In.	Strength Values Lb.Sq.In.	Notes
Compressive	1/8"	Alternate	Single	.77	500	7,890	
	1/16"	Alternate	Single	.72	500	7,980	
	1/48"	Alternate	Single	.77	200	8,580	
	1/48"	Alternate	Single	1.05	500	11,720	2
	1/48"	Every 5th	Single	.73	500	12,130	3
	1/48"	Every 10th	Single	.77	500	13,040	3
	1/48"	Alternate	Double	1.10	500	13,300	
	1/48"	Alternate	Single	1.30	1,000	14,220	
	1/48"	Alternate	Single	1.35	1,500	14,540	1
Tensile	1/8"	Alternate	Single	.77	500	11,840	
	1/48"	Alternate	Single	.77	200	12,550	
	1/16"	Alternate	Single	.72	500	13,920	
	1/48"	Alternate	Single	1,05	500	19,160	2
	1/48"	Every 5th	Single	.73	500	19,370	3
	1/48"	Alternate	Double	1.10	500	19,800	
	1/48"	Every 10th	Single	.77	500	19,920	3
	1/48"	Alternate	Single	1.30	1,000	25,740	
	1/48"	Alternate	Single	1.35	1,500	28,490	1
Shear	1/8"	Alternate	Single	.77	500	6,060	
	1/16"	Alternate	Single	.72	500	6,330	
	1/48"	Alternate	Single	.77	200	7,240	
	1/48"	Every 10th	Single	.77	500	8,370	3
	1/48"	Every 5th	Single	.73	500	8,480	3
	1/48"	Alternate	Single	1.05	500	11,540	2
	1/48"	Alternate	Double	1.10	500	14,520	
	1/48"	Alternate	Single	1.30	1,000	16,180	
	1/48"	Alternate	Single	1.35	1,500	16,360	1

Notes: 1. Increase of pressure, 1,000 to 1,500 pounds per square inch, gives little added strength.

2. Basic standard of this series of tests.

3. Difference between crossing every fifth and tenth layer is not significant.

Table 8.

EXTRA - DENSE NORMAL SOLID WOODS AND

APPROXIMATE EQUIVALENTS IN HIGH DENSITY PLYWOOD.

Species	Specific Gravity (a)	
	Range	Average
Apple	0.66 - 0.84	0.75
Beech	0.70 - 0.90	0.80
Boxwood	0.95 - 1.16	1.05
Dogwood	0.68 - 0.77	0.72
Ebony	1.11 - 1.33	1.22
Hickory	0.62 - 0.78	0.70
Hornbeam	. . . .	0.75
Lancewood	0.68 - 1.00	0.84
Lignum Vitae	1.17 - 1.33	1.25
White Oak	0.69 - 0.86	0.77
Satinwood	. . . .	0.95
Teak	0.66 - 0.98	0.82

PlywoodConstruction (b)	Film Layers	Specific Pressure Lb.Sq.In.	Specific Gravity
17/16" Birch	Single	500	0.72
45/40" Gum, red	Single	500	0.73
57/48" Birch	Single	200	0.77
77/45" Poplar	Single	500	0.82
69/48" Birch	Single	500	1.05
73/48" Birch	Double	500	1.105
81/48" Birch	Single	1,000	1.30
105/45" Poplar	Single	1,500	1.32
85/48" Birch	Single	1,500	1.36

(a) Specific Gravity from Kent's Handbook, 1938 edition.

(b) All constructions are standard alternate crossings.

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